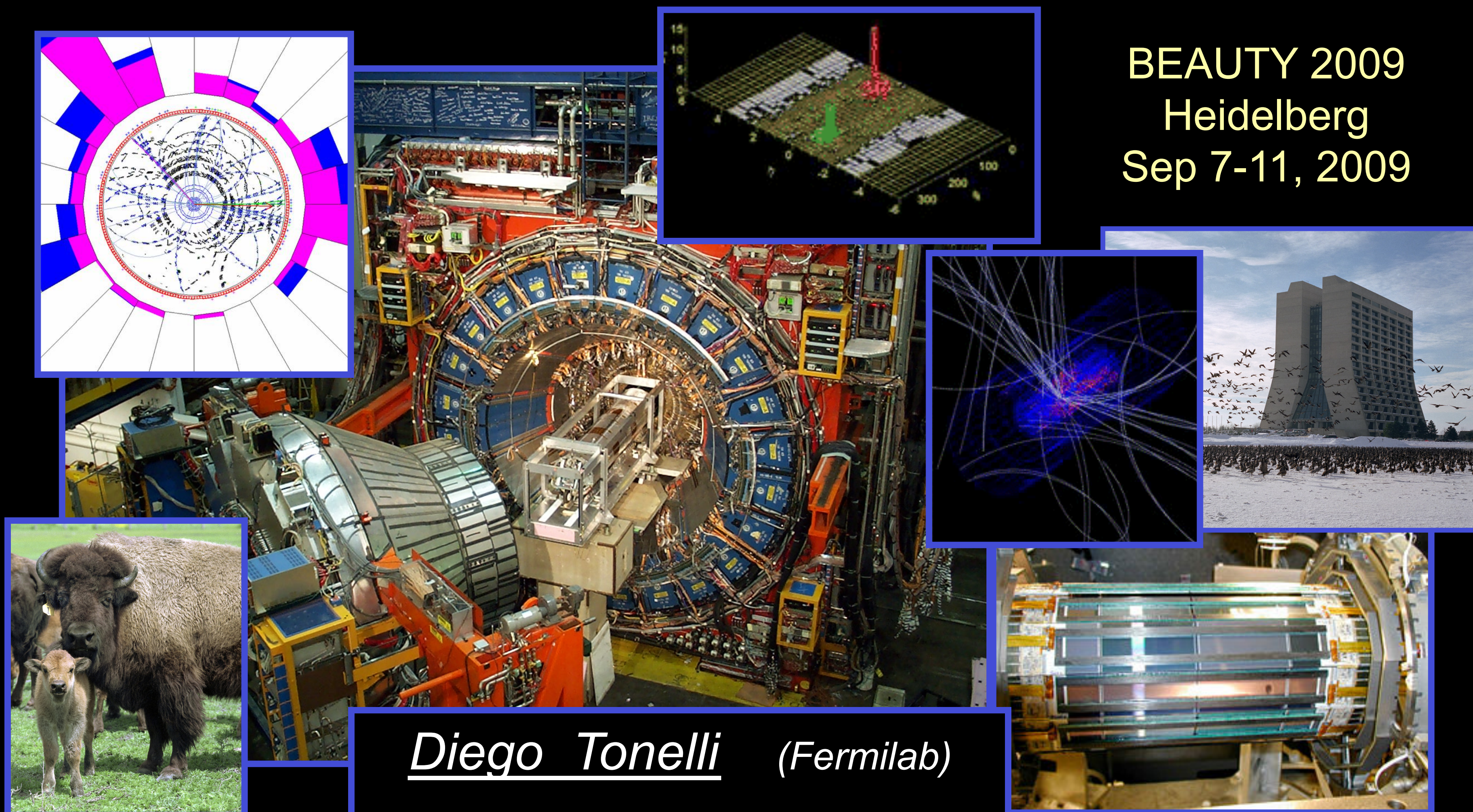
Charmless B decays at CDF



BEAUTY 2009
Heidelberg
Sep 7-11, 2009

<u>Diego Tonelli</u> *(Fermilab)*

for the CDF Collaboration

Merriam-Webster dictionary

Main Entry: ¹**charm**

Pronunciation: \'chärm\

Function: *noun*

Etymology: Middle English *charme,* from Anglo-French, from Latin *carmen* song, from *canere* to sing — more at CHANT

Date: 14th century

1 a : the chanting or reciting of a magic spell **:** INCANTATION **b :** a practice or expression believed to have magic power

2 : something worn about the person to ward off evil or ensure good fortune **:** AMULET

3 a : a trait that fascinates, allures, or delights **b :** a physical grace or attraction —used in plural <her feminine *charms*> **c :** compelling attractiveness <the island possessed great *charm*>

4 : a small ornament worn on a bracelet or chain

5 : a fundamental quark that has an electric charge of $+^{2}/_{3}$ and a measured energy of approximately 1.5 GeV; *also* **:** the flavor characterizing this particle

— **charm·less** \-ləs\ *adjective*

Charmless *B* decays

Most popular processes in HF. Many open channels into similar final states allow constraining hadronic unknowns. $b \rightarrow u$ sensitive to CKM angle γ. Penguins enhance sensitivity to NP in loops.

V On the Autonomy of B_s Dynamics

original paradigm: need B_d & B_s to determine all 3 angles

ϕ_2/α, ϕ_1/β from B_d vs. ϕ_3/γ from B_s

new paradigm: can get all angles from B_d

Furthermore NP in general will not obey SM relations between B and B_s decays

➥ B_s decays a priori independent chapter in nature's book on fundamental dynamics

$B_s(t) \rightarrow \psi\phi$, $\psi\eta$, $\phi\phi$ not a repetition of lessons from B_d & B_u decays!

stolen from I. Bigi, CERN Theory Institute, May 26, 2008

CDF a.k.a. charmless B^0_s pioneers

PRL **95,** 031801 (2005) PHYSICAL REVIEW LETTERS week ending 15 JULY 2005

Evidence for $B^0_s \to \phi\phi$ Decay and Measurements of Branching Ratio and A_{CP} for $B^+ \to \phi K^+$

PRL **97,** 211802 (2006) PHYSICAL REVIEW LETTERS week ending 24 NOVEMBER 2006

Observation of $B^0_s \to K^+K^-$ and Measurements of Branching Fractions of Charmless Two-Body Decays of B^0 and B^0_s Mesons in $\bar{p}p$ Collisions at $\sqrt{s} = 1.96$ TeV

PRL **103,** 031801 (2009) PHYSICAL REVIEW LETTERS week ending 17 JULY 2009

Observation of New Charmless Decays of Bottom Hadrons

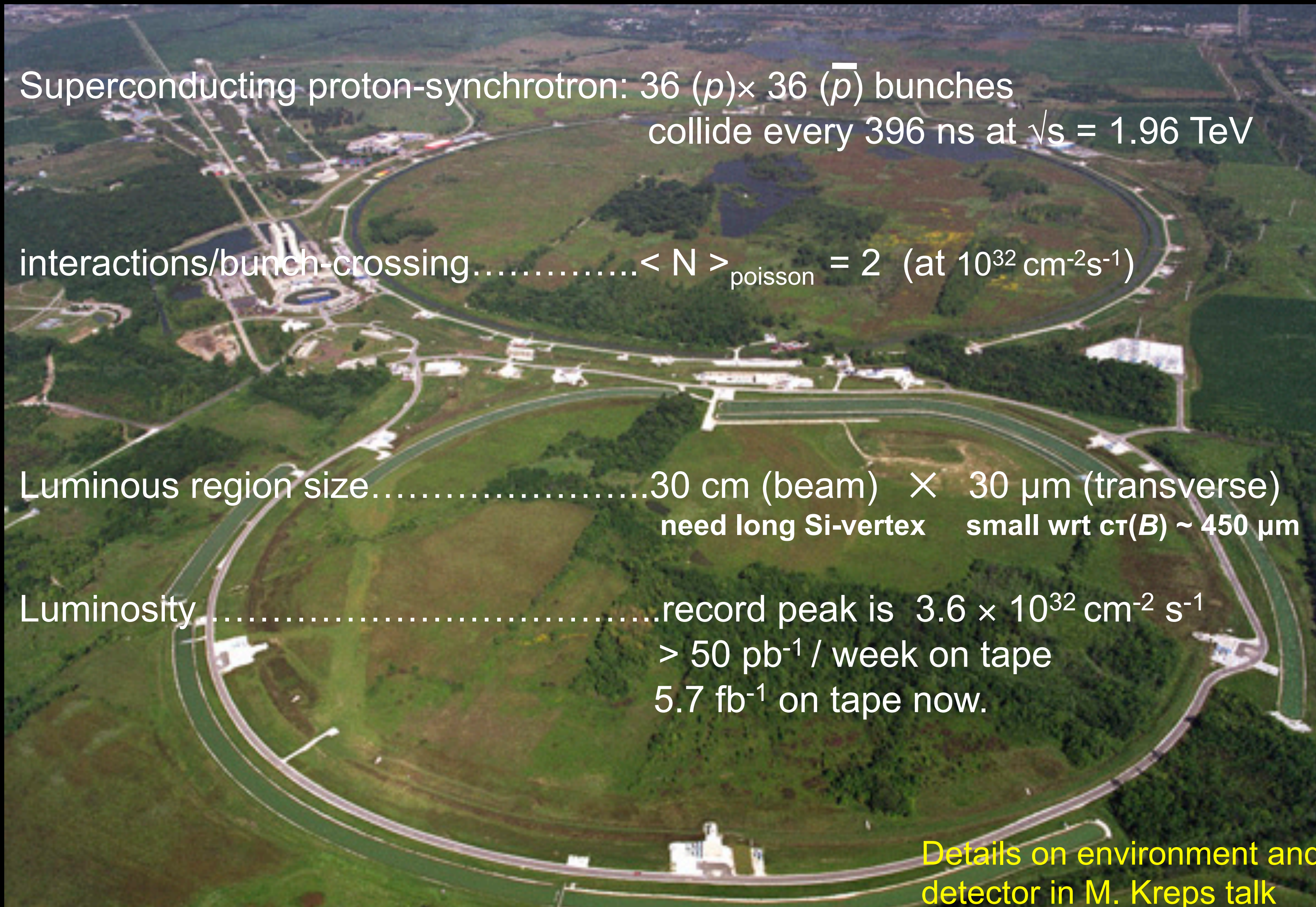
This talk

Recent update of $B^0_s \to \phi\phi$ analysis;

Results on $B^0_{(s)} \to h^+h^-$ decays;

Prospects.

The Tevatron



Superconducting proton-synchrotron: 36 (p)$\times$ 36 ($\bar{p}$) bunches
collide every 396 ns at $\sqrt{s}$ = 1.96 TeV

interactions/bunch-crossing…………..$\langle N \rangle_{poisson}$ = 2 (at 10^{32} $cm^{-2}s^{-1}$)

Luminous region size…………………..30 cm (beam) $\times$ 30 μm (transverse)

need long Si-vertex **small wrt cτ(*B*) ~ 450 μm**

Luminosity……………………………….record peak is 3.6×10^{32} cm^{-2} s^{-1}

> 50 pb^{-1} / week on tape

5.7 fb^{-1} on tape now.

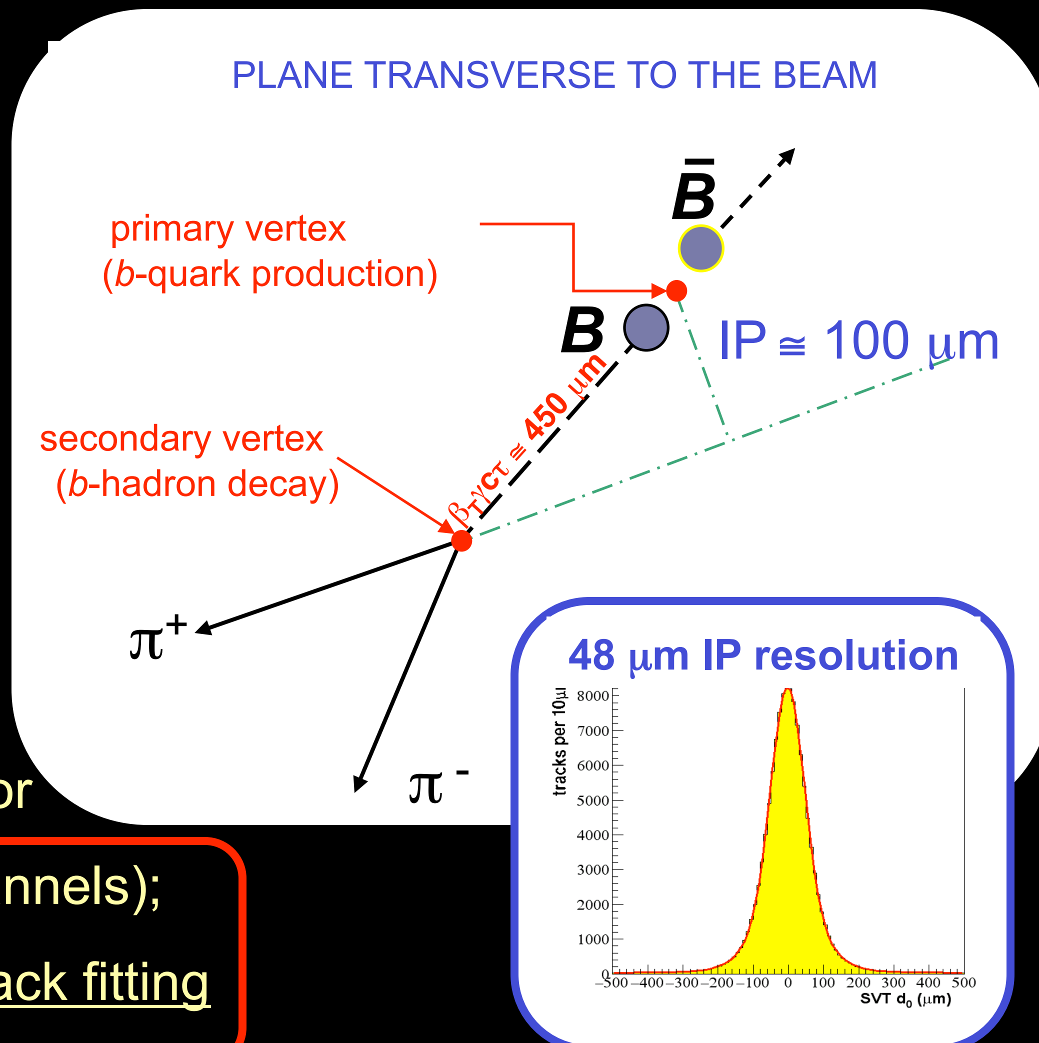
Details on environment and detector in M. Kreps talk

Hadronic trigger

1.5 ps lifetime of *b*-hadrons: a powerful signature.

Sufficiently boosted *B* fly a path resolvable with vertex detectors before decaying.

Exploit it at the trigger level - an experimental challenge that requires:



(1) high resolution vertex detector

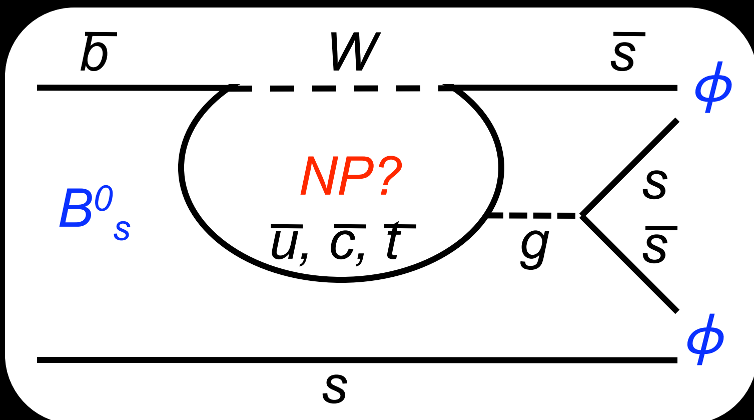
(2) read out silicon (212,000 channels);

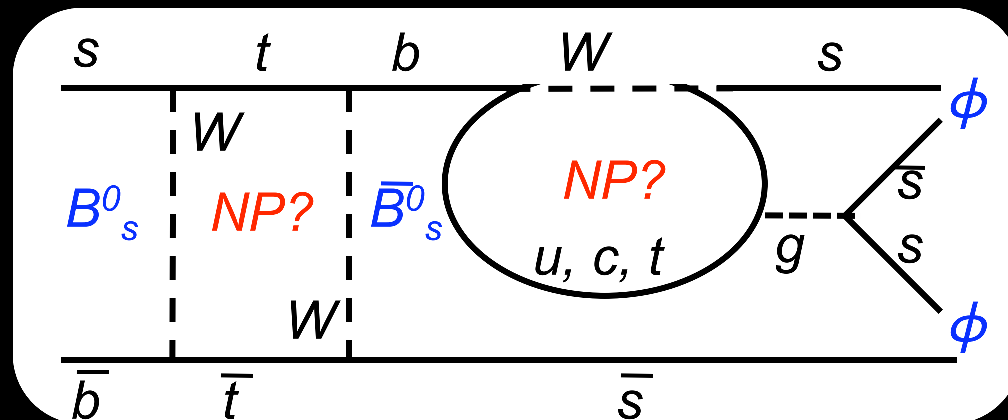
(3) do pattern recognition and track fitting

within 25 μs

$$B^0_s \rightarrow \phi\phi$$

NP the penguin way





Angular analysis of time-evolution of flavor tagged decays: independent probe on $sin2\beta_s$ to be compared with $B^0_s \to J/\psi\phi$ determination.

	B^0	B^0_s	where NP can enter?
$b \to c\bar{c}s$	$B^0 \to J/\psi K^0_s$	$B^0_s \to J/\psi\phi$	mixing
$b \to s\bar{s}s$	$B^0 \to \phi K^0_s$, $B^0 \to \eta' K^0_s$	$B^0_s \to \phi\phi$	mixing or penguin

Lots of statistics required. Polarization analysis already sensitive to NP.

Status

Some theory predictions

BR ~ 0.4-25 $\times 10^{-6}$ PRD 59, 074003 (1999)

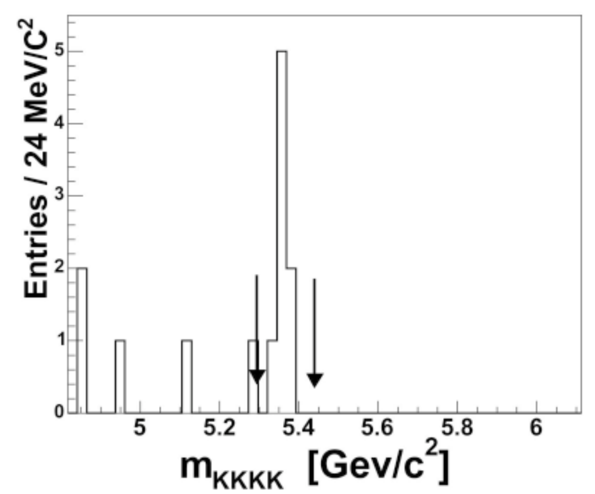
BR ~ 37 $\times 10^{-6}$ PRD 68, 114015 (2003)

First (and only) evidence, CDF 2005

180 pb^{-1}, 8 signal events

BR = $(14\ ^{+6}_{-5} \pm 6) \times 10^{-6}$

PRL 95, 031801 (2005)



…some "post-dictions"

BR ~ 18-60 $\times 10^{-6}$ PRD 76, 074018 (2007)

BR ~ 4-53 $\times 10^{-6}$ NPB 774, 64 (2007)

CDF has now accumulated a factor of ~25 more in statistics

The measurement

Fit to mass in data

2.9 fb^{-1}

$$\frac{\mathrm{BR}(B_s^0 \to \phi\phi)}{\mathrm{BR}(B_s^0 \to J/\psi\phi)} = \boxed{\frac{N_{\phi\phi}}{N_{\psi\phi}}}\boxed{\frac{\mathrm{BR}(J/\psi \to \mu\mu)}{\mathrm{BR}(\phi \to KK)}}\boxed{\frac{\epsilon_{\psi\phi}}{\epsilon_{\phi\phi}}}\boxed{\epsilon^{\mu}_{\psi\phi}},$$

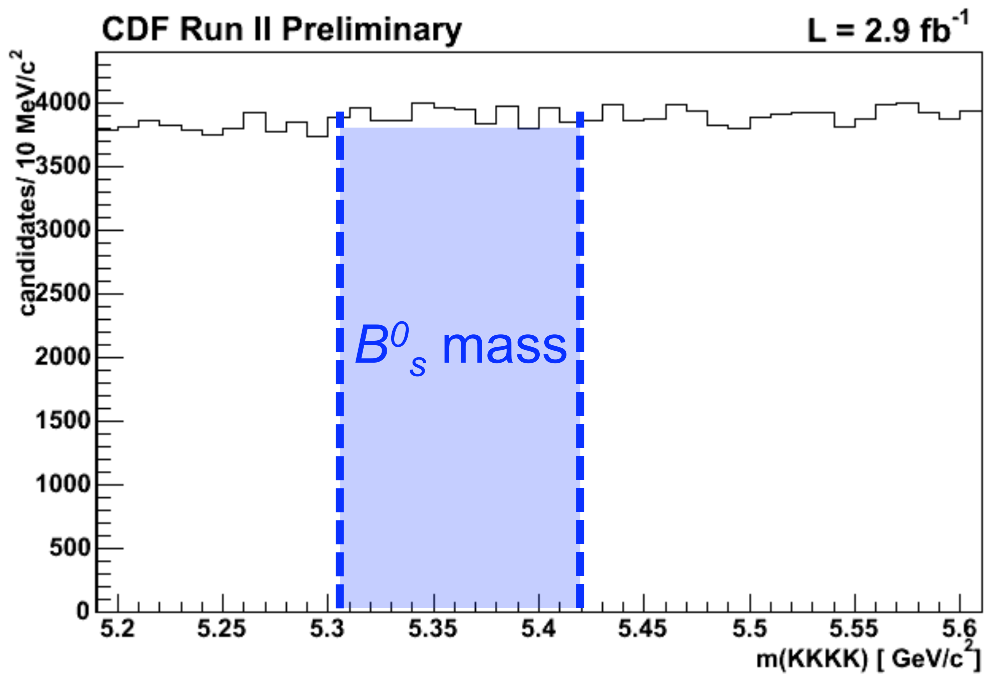
PDG

Trigger and selection acceptance/efficiency from simulation

Muon-ID efficiency from control samples of data

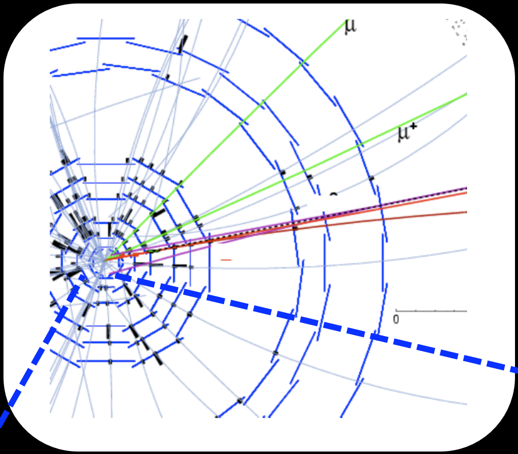
Use $B^0_s \to J/\psi\phi$ as a reference rather than e.g. $B^0 \to \phi K^*$. Avoid dependence on fragmentation probabilities f_s/f_d

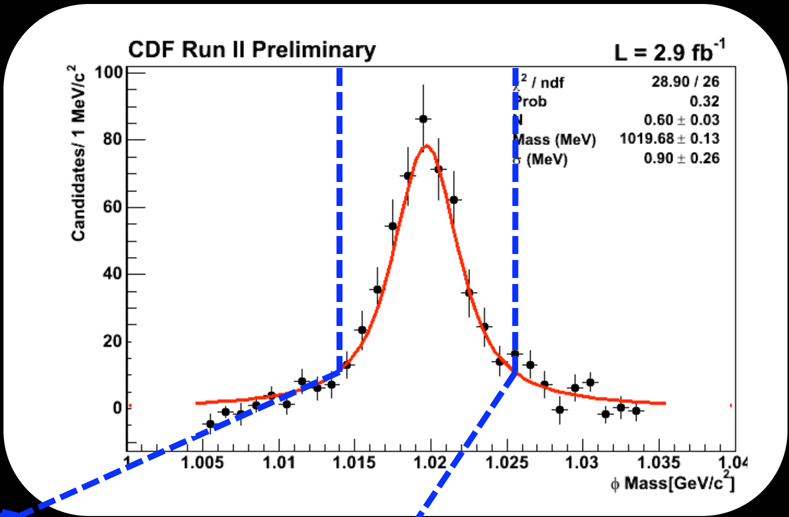
Fresh off the trigger



$\phi\phi$-mass after trigger cuts

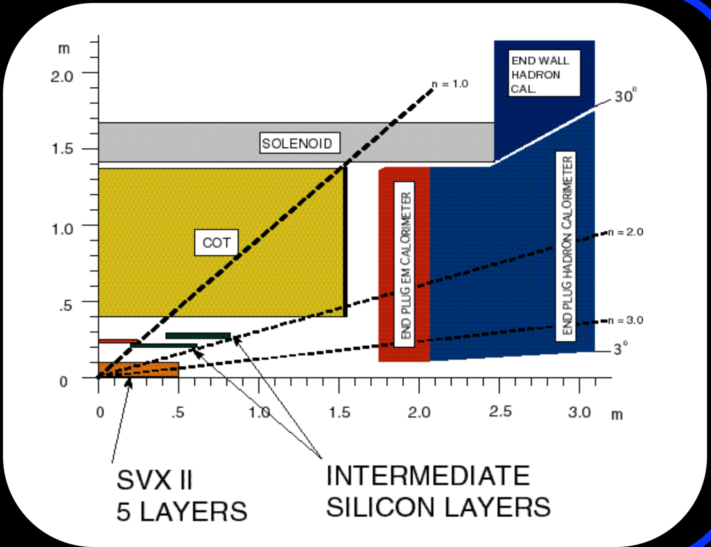
All you need is tracking





1.4T in 132 cm lever-arm. 96 drift chamber + 6 silicon samplings.

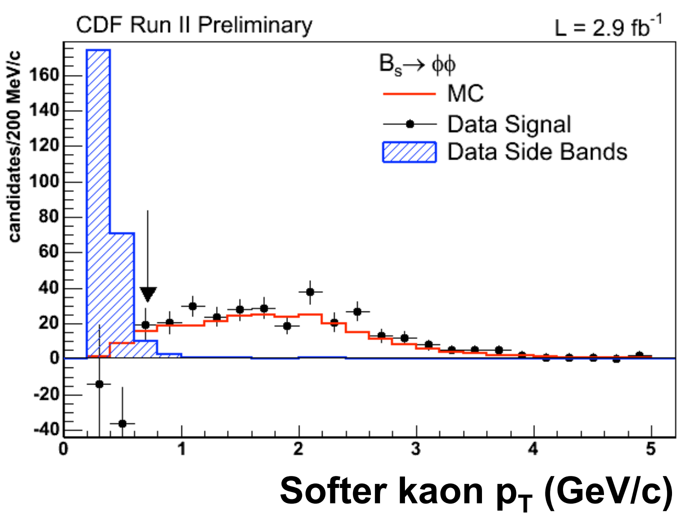
1st layer 1.5 cm from beam

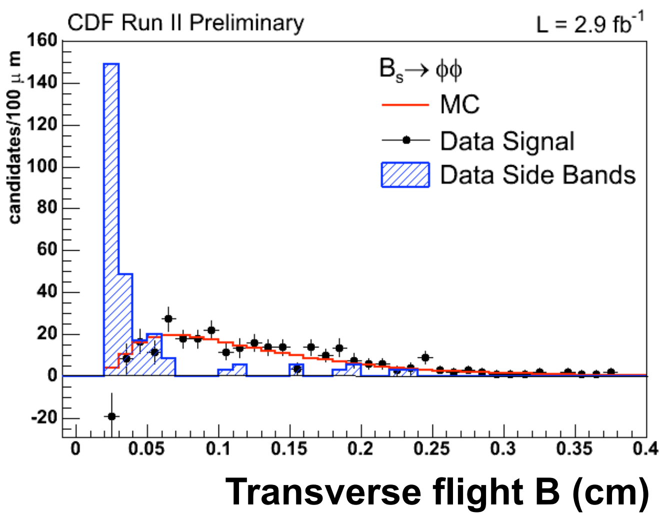


Optimizing the selection

Unbiased maximization of $S/\sqrt{S+B}$.

S is # of simulated events. B is # background events extrapolated from mass sidebands. Done separately for signal and reference mode.





Look for stiff kaons

Look for long-lived

The signal

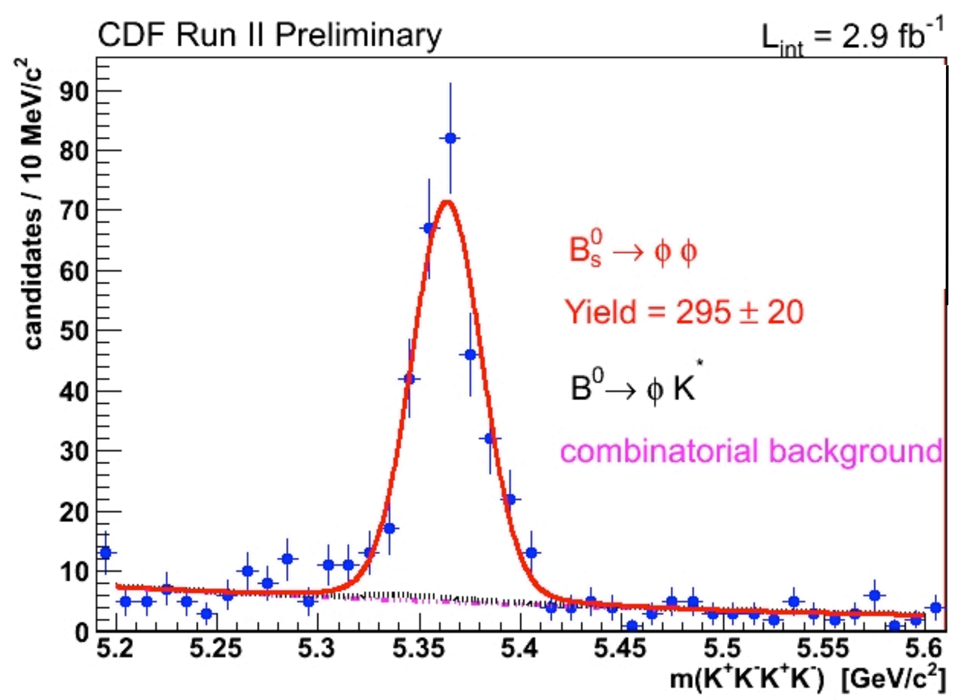
L_{xy}> 330 μm

IP_{max}(K) > 85 μm

IP(B) < 65 μm

p_T(K) > 0.7 GeV/c

Vtx χ^2< 17



Backgrounds

✓ Combinatorics dominant

✓ 2.5% $B^0 \to \phi K^{*0}$ reflection

✓ $B^0{}_s \to K^{*0}\, K^{*0}$ negligible

40✕ increase in statistics since published result

Optimized reference ($B^0_s \to J/\psi\phi$)

L_{xy} > 290 μm

IP(B) < 65 μm

Vtx χ^2 < 18

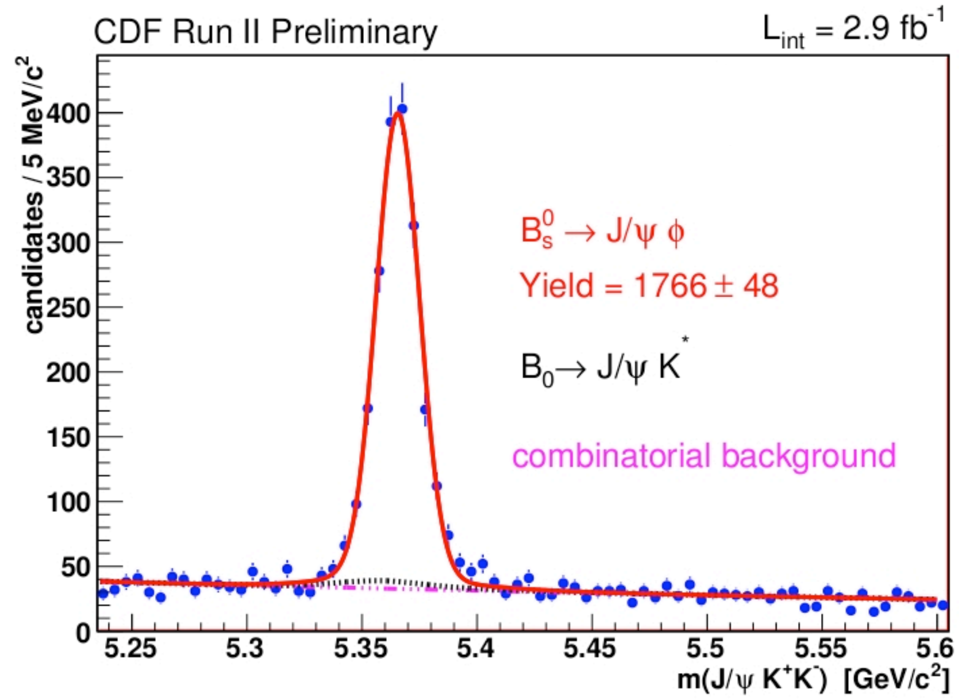
$p_T(J/\psi)$ > 2.0 GeV/c

$p_T(\phi)$ > 1.4 GeV/c

Backgrounds

Combinatorics dominant

4% $B^0 \to J/\psi K^{*0}$ reflections



Aside: this adds +25% to sample collected in di-muon trigger.
Increase statistics for $sin2\beta_s$ analysis.

Relative efficiency: trigger and selection

$$\frac{\mathrm{BR}(B_s^0 \to \phi\phi)}{\mathrm{BR}(B_s^0 \to J/\psi\phi)} = \frac{N_{\phi\phi}}{N_{\psi\phi}} \frac{\mathrm{BR}(J/\psi \to \mu\mu)}{\mathrm{BR}(\phi \to KK)} \boxed{\frac{\epsilon_{\psi\phi}}{\epsilon_{\phi\phi}}} \epsilon^{\mu}_{\psi\phi},$$

Simulated signal reweighted in $p_T(B)$ and to reproduce trigger mix of data.

$$\frac{\epsilon_{\psi\phi}}{\epsilon_{\phi\phi}} = 0.939 \pm 0.030 \pm 0.009$$

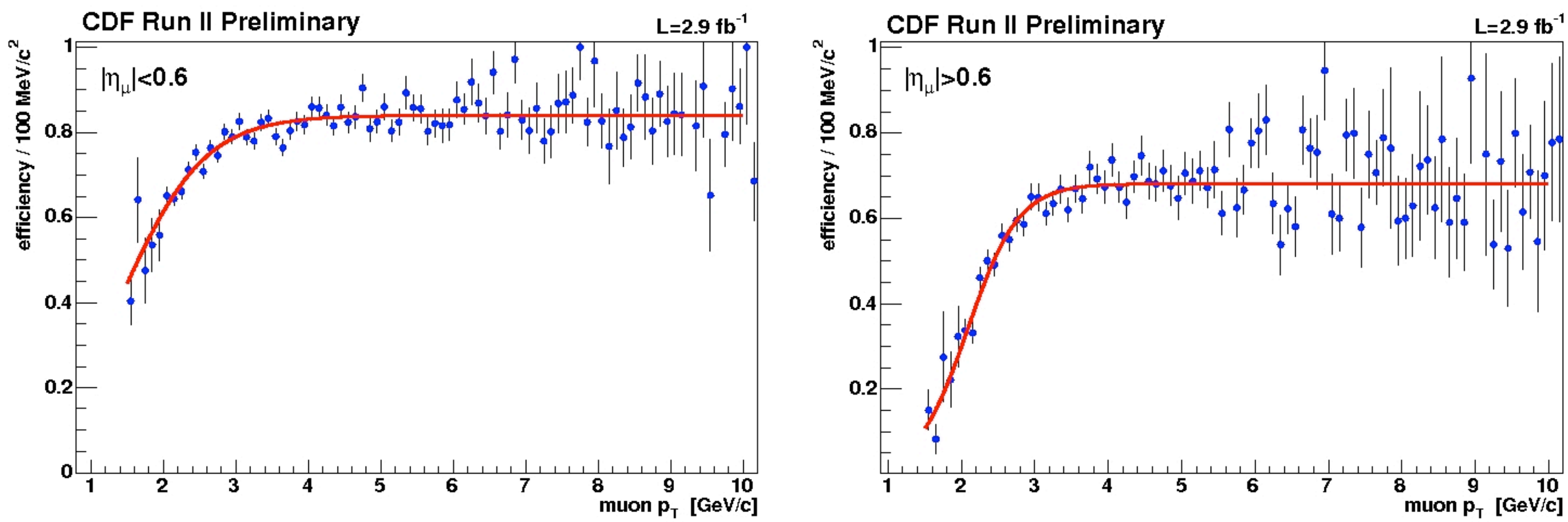
- ✓ First uncertainty: finite statistics collected by each trigger.
- ✓ Second uncertainty: reweighing.

Relative efficiency: muon-ID

$$\frac{\mathrm{BR}(B_s^0 \to \phi\phi)}{\mathrm{BR}(B_s^0 \to J/\psi\phi)} = \frac{N_{\phi\phi}}{N_{\psi\phi}} \frac{\mathrm{BR}(J/\psi \to \mu\mu)}{\mathrm{BR}(\phi \to KK)} \frac{\epsilon_{\psi\phi}}{\epsilon_{\phi\phi}} \boxed{\epsilon^{\mu}_{\psi\phi}},$$

$$\epsilon^{\mu}_{\psi\phi} = 0.8695 \pm 0.0044(\mathrm{stat})$$

Extracted from *J/ϕ* data as a function of p_T and muon-detector



Systematic uncertainties

- ✓ 6-7% from unknown polarization of $B \to VV$, which impacts acceptance;
- ✓ 3-4% from K/μ difference in trigger efficiency due to different ionization probability in the tracking chamber;
- ✓ 3% signal mass parameterization;
- ✓ 3% unmodeled backgrounds;
- ✓ 1% from p_T reweighing, background subtraction etc…

$$
\begin{aligned}
N_{\phi\phi} &= 295 \pm 20(\text{stat}) \pm 12(\text{syst}) \\
N_{J/\psi\phi} &= 1766 \pm 48(\text{stat}) \pm 41(\text{syst})
\end{aligned}
$$

Results

$$\frac{BR(B_s^0 \to \phi\phi)}{BR(B_s^0 \to J/\psi\phi)} = [1.78 \pm 0.14(stat) \pm 0.20(syst)] \cdot 10^{-2}$$

Use BR($B^0_s \to J/\psi\phi$) from PDG, updated to current values of f_s/f_d

$$BR(B_s^0 \to \phi\phi) = [2.40 \pm 0.21(stat) \pm 0.27(syst) \pm 0.82(BR)] \cdot 10^{-5}$$

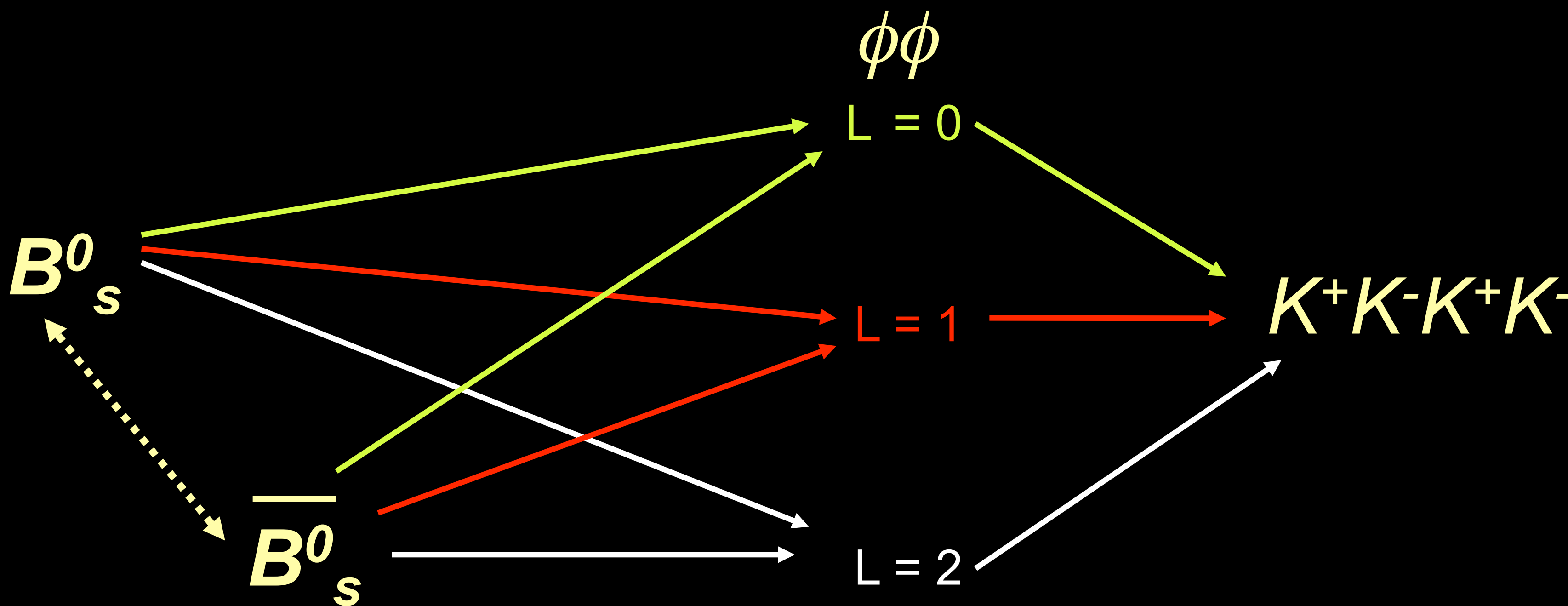
Compare with (BR/10^{-5})

previous CDF result	$1.4\,^{+0.6}_{-0.5} \pm 0.6$	PRL 95 031801 (2005)
theory (QCDF)	$2.18 \pm 0.1\,^{+3.04}_{-1.78}$	NP B774, 64, (2007)
theory (pQCD)	$3.53\,^{+0.83}_{-0.69}\,^{+1.67}_{-1.02}$	PR D76, 074018 (2007)

Next

Working at the polarization analysis.

B^0_s (pseudoscalar) $\rightarrow \phi$ (vector) ϕ (vector). Final states CP-even (S- or D-wave, short-lived and light) and CP-odd (P-wave, long-lived, heavy).



Rich structure: presence of both CP-states provides additional information on underlying dynamics and sensitivity to NP.

Polarization

Anomaly: measured $f_T=1 - f_L \sim 0.5$ in $B^{0(+)} \to \phi K^{*(+)}$ disagree with 1st order estimate from theory

$$\bar{A}_0 : \bar{A}_- : \bar{A}_+ = 1 : \frac{\Lambda}{m_b} : \left(\frac{\Lambda}{m_b}\right)^2 \qquad 1 - f_L = \mathcal{O}\left(\frac{m_V^2}{m_B^2}\right), \qquad \frac{f_\perp}{f_\parallel} = 1 + \mathcal{O}\left(\frac{m_V}{m_B}\right)$$

"Ad hoc" SM solutions: annihilation **PL B601, 151 (2004)**, transverse gluon **hep-ph/0408007** , EM penguin **PRL 96, 141801 (2006)** , charming penguins **PR D70, 054015 (2004)**, long-distance re-scattering **PR D71, 014030(2005),**

All above are model dependent or not conclusive: NP option still valid: e.g. scalar interaction or SUSY would introduce $1+\gamma^5$ terms in amplitude.

Further experimental info key to discriminate. $B^0_s \to \phi\,\phi$ + SU(3) checks for "penguin annihilation" **EPJ C60 (2009)**

Analysis in progress - $O(5\%)$ resolution on amplitudes expected.

$$B^0_{(s)} \rightarrow h^+ h'^-$$

Two-body charmless decays

B^0 and $B^0_s \rightarrow K^+K^-$, $\pi^+\pi^-$, $K\pi$ and sensitive to γ (**PL B459, 306 (1999)**) and NP (**PL B492, 297 (2000), PL B621,126, (2005)**). Theory and exp. uncertainties largely cancel thanks to flavor symmetries and similar final states.

CDF has world's largest sample:

4K $B^0 \rightarrow K^+\pi^-$ and 1.3K $B^0_s \rightarrow K^+K^-$ per fb^{-1}.

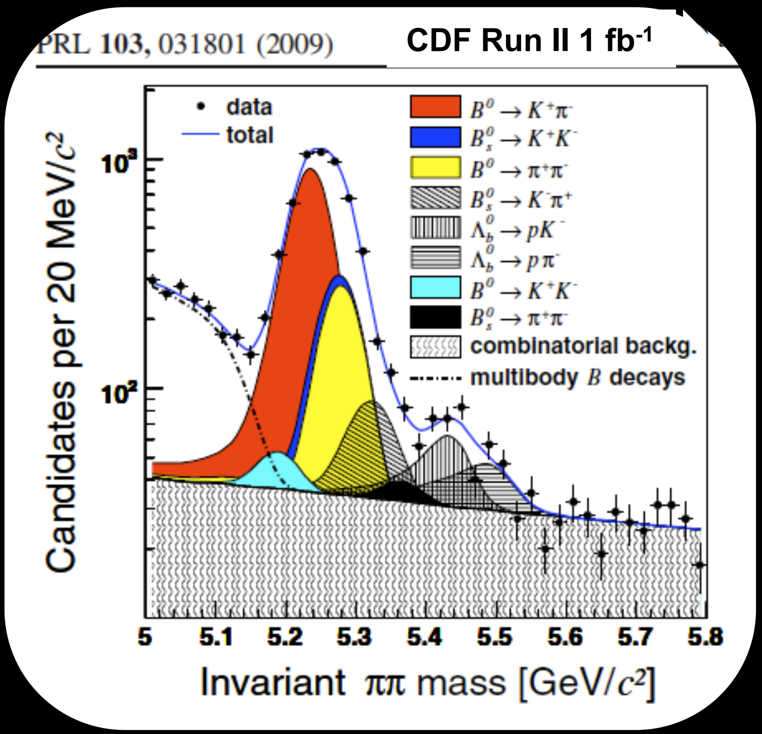
Unique joint access to large samples of charmless B^0 and B^0_s

Challenging analysis but fruitful:

✓ observation of 4 new modes (so far)

✓ unique access to direct CPV in B^0_s

✓ competitive in direct CPV in B^0



Two-body charmless results (1 fb^{-1})

PRL103, 031801 (2009)

Mode	Relative $\mathcal{B}$	Absolute $\mathcal{B}(10^{-6})$
$B_s^0 \to K^-\pi^+$	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0\to K^-\pi^+)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.071 \pm 0.010 \pm 0.007$	$5.0 \pm 0.7 \pm 0.8$
$B_s^0 \to \pi^+\pi^-$	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0\to \pi^+\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.007 \pm 0.004 \pm 0.005$	$0.49 \pm 0.28 \pm 0.36$ (<1.2 at 90% C.L.)
$B^0 \to K^+K^-$	$\frac{\mathcal{B}(B^0\to K^+K^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.020 \pm 0.008 \pm 0.006$	$0.39 \pm 0.16 \pm 0.12$ (<0.7 at 90% C.L.)
$\Lambda_b^0 \to pK^-$	$\frac{f_\Lambda}{f_d}\frac{\mathcal{B}(\Lambda_b^0\to pK^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.066 \pm 0.009 \pm 0.008$	$5.6 \pm 0.8 \pm 1.5$
$\Lambda_b^0 \to p\pi^-$	$\frac{f_\Lambda}{f_d}\frac{\mathcal{B}(\Lambda_b^0\to p\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.042 \pm 0.007 \pm 0.006$	$3.5 \pm 0.6 \pm 0.9$

world first

world best

submitted soon

Mode	Relative $\mathcal{B}$	Absolute $\mathcal{B}(10^{-6})$
$B^0 \to \pi^+\pi^-$	$\frac{\mathcal{B}(B^0\to\pi^+\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.259 \pm 0.017 \pm 0.016$	$5.02 \pm 0.33 \pm 0.35$
$B_s^0 \to K^+K^-$	$\frac{f_s}{f_d}\frac{\mathcal{B}(B_s^0\to K^+K^-)}{\mathcal{B}(B^0\to K^+\pi^-)} = 0.347 \pm 0.020 \pm 0.021$	$24.4 \pm 1.4 \pm 3.5$

Mode	CP–asymmetry
$B^0 \to K^+\pi^-$	$\frac{\mathcal{B}(\overline{B}^0\to K^-\pi^+)-\mathcal{B}(B^0\to K^+\pi^-)}{\mathcal{B}(\overline{B}^0\to K^-\pi^+)+\mathcal{B}(B^0\to K^+\pi^-)} = -0.086 \pm 0.023 \pm 0.009$
$B_s^0 \to K^-\pi^+$	$\frac{\mathcal{B}(\overline{B}_s^0\to K^+\pi^-)-\mathcal{B}(B_s^0\to K^-\pi^+)}{\mathcal{B}(\overline{B}_s^0\to K^+\pi^-)+\mathcal{B}(B_s^0\to K^-\pi^+)} = +0.39 \pm 0.15 \pm 0.08$
$\Lambda_b^0 \to pK^-$	$\frac{\mathcal{B}(\Lambda_b^0\to pK^-)-\mathcal{B}(\overline{\Lambda}_b^0\to \overline{p}K^+)}{\mathcal{B}(\Lambda_b^0\to pK^-)+\mathcal{B}(\overline{\Lambda}_b^0\to \overline{p}K^+)} = +0.37 \pm 0.17 \pm 0.03$
$\Lambda_b^0 \to p\pi^-$	$\frac{\mathcal{B}(\Lambda_b^0\to p\pi^-)-\mathcal{B}(\overline{\Lambda}_b^0\to \overline{p}\pi^+)}{\mathcal{B}(\Lambda_b^0\to p\pi^-)+\mathcal{B}(\overline{\Lambda}_b^0\to \overline{p}\pi^+)} = +0.03 \pm 0.17 \pm 0.05$

Next

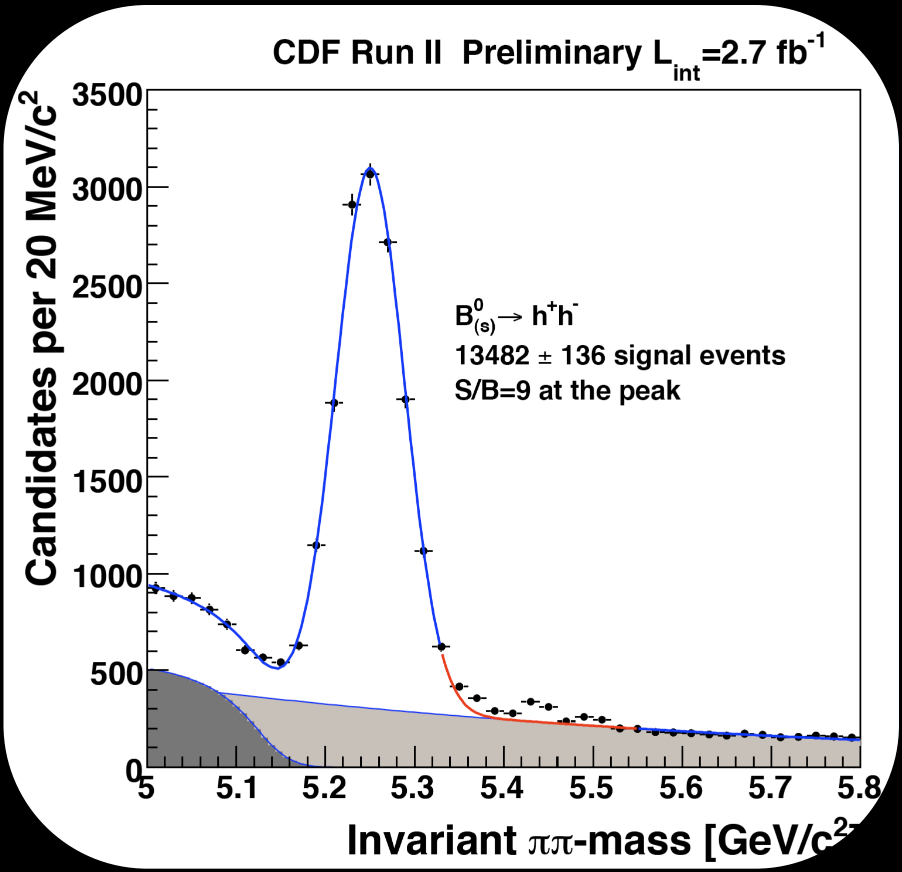
5 fb^{-1} analysis in progress

✓ Expect observation of DCPV in B^0_s.

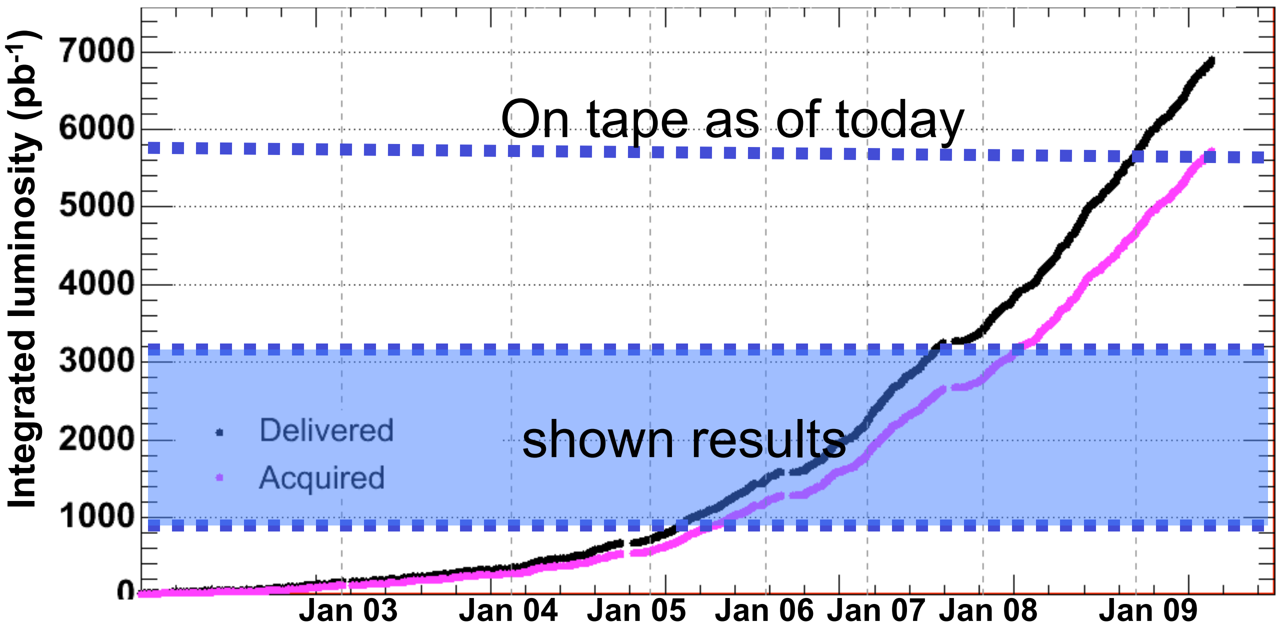
✓DCPV in B^0 competitive with Belle.

✓ Precision measurement of rare modes' BR.

✓ Observe new modes? (aim at $B^0_s \rightarrow \pi^+\pi^-$)



Outlook



More than 8 fb^{-1} of physics-quality data on tape by end of 2010.
10 fb^{-1} by 2011, if Run II further extended.

2.7x-8x (3.5x-10x) increase in currently analyzed samples.

Summary and conclusions

CDF keep harvesting from rich and unique program on charmless B^0_s .

Recent 2.9 fb^{-1} update of $B^0_s \to \phi\phi$ – NP in $b \to s\bar{s}s$ penguin or mixing:

✓ ~halved BR uncertainty. Polarization analysis in progress.

Charmless $B^0_{(s)} \to h^+h^-$ - test for NP and constrain hadronic unknowns for γ from penguins:

✓ Many new decays observed - BR and DCPV measured. 5 fb^{-1} analysis in progress.

Only 1/8 – 1/3 of data expected by end 2010 shown. Analyses steadily improving. Psychological advantage: lots of data, complex analyses already set up, all pressure is on CERN.

Sitting on goldmine of data: a few exciting years of competition with LHCb are coming.

Collider Detector at Fermilab

ARS GRATIA ARTIS

TRADE MARK

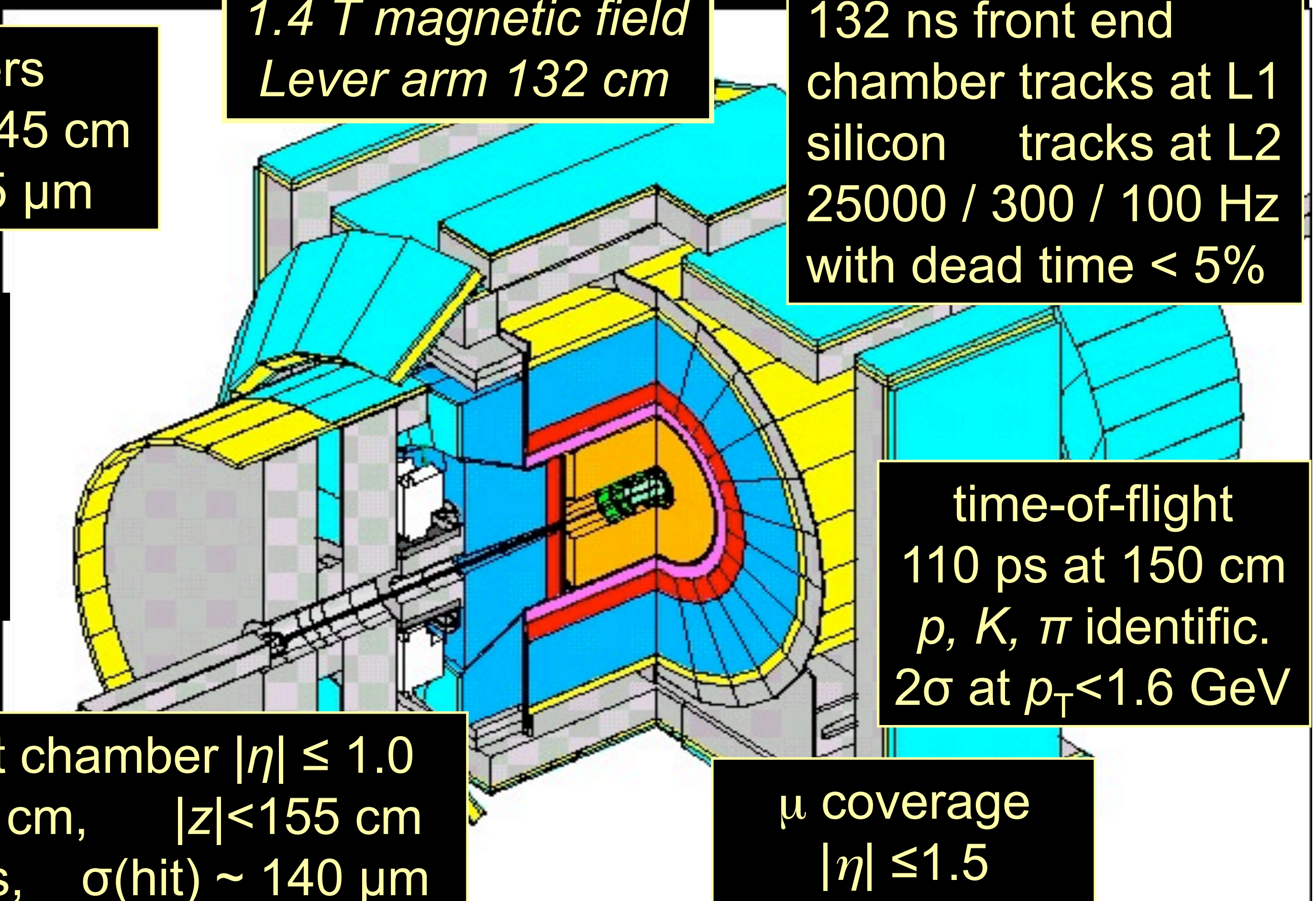
www-cdf.fnal.gov

The CDF II detector

7 to 8 silicon layers
$1.6 < r < 28$ cm, $|z|<45$ cm
$|\eta| \leq 2.0$ σ(hit) ~ 15 μm

1.4 T magnetic field
Lever arm 132 cm

132 ns front end
chamber tracks at L1
silicon tracks at L2
25000 / 300 / 100 Hz
with dead time < 5%



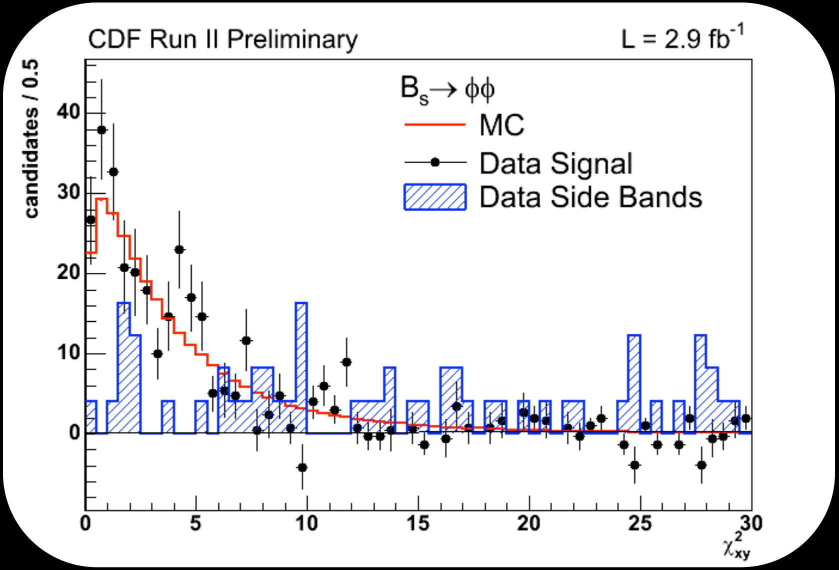
Some resolutions:
p_T~0.15% p_T (c/GeV)
J/Ψ mass ~14 MeV
IP~ 40 μm
(includes beam spot)

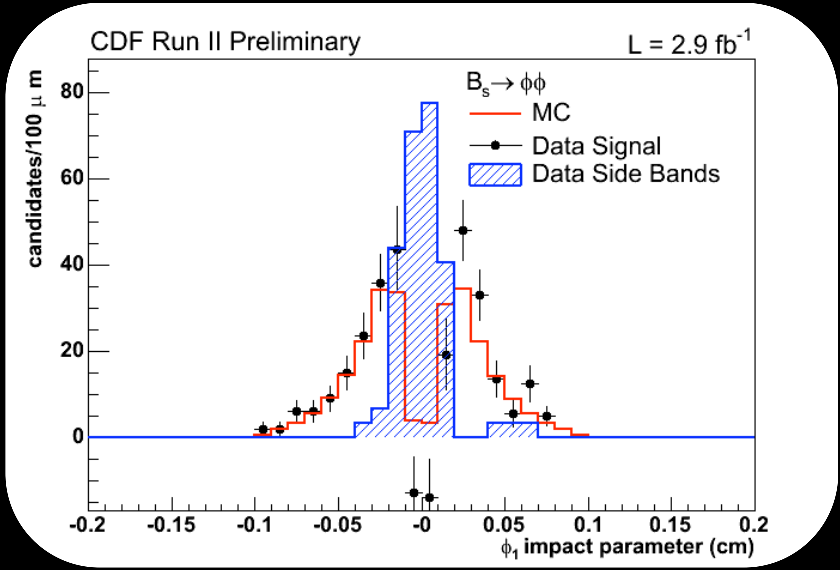
time-of-flight
110 ps at 150 cm
p, K, π identific.
2σ at p_T<1.6 GeV

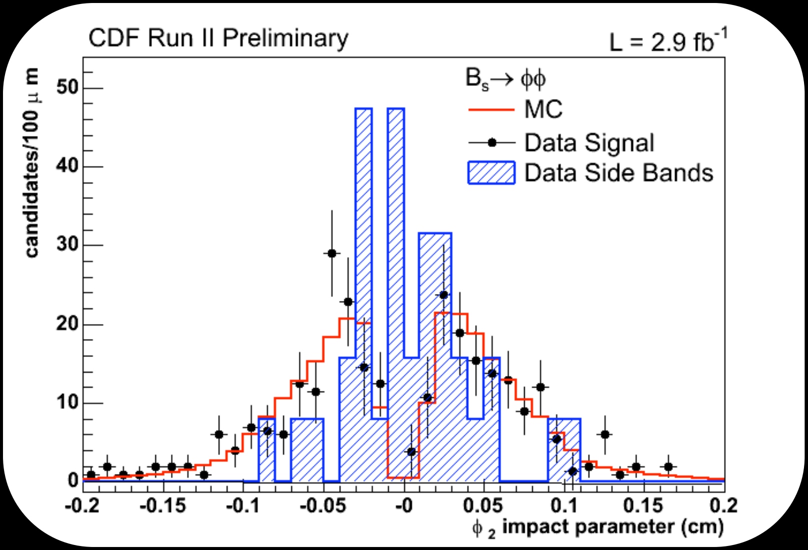
96 layer drift chamber $|\eta| \leq 1.0$
$44 < r < 132$ cm, $|z|<155$ cm
30k channels, σ(hit) ~ 140 μm
dE/dx for p, K, π identification

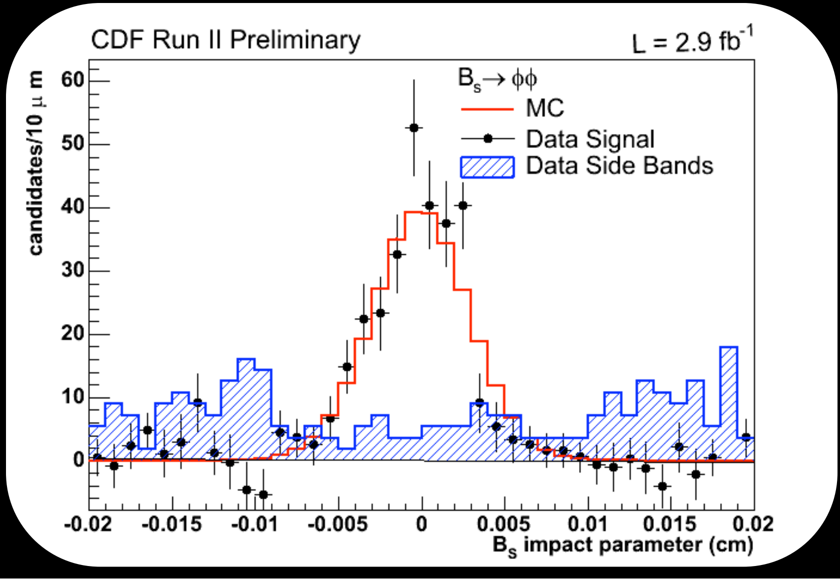
μ coverage
$|\eta| \leq 1.5$
84% in φ

$B^0_s \to \phi\phi$ - optimization

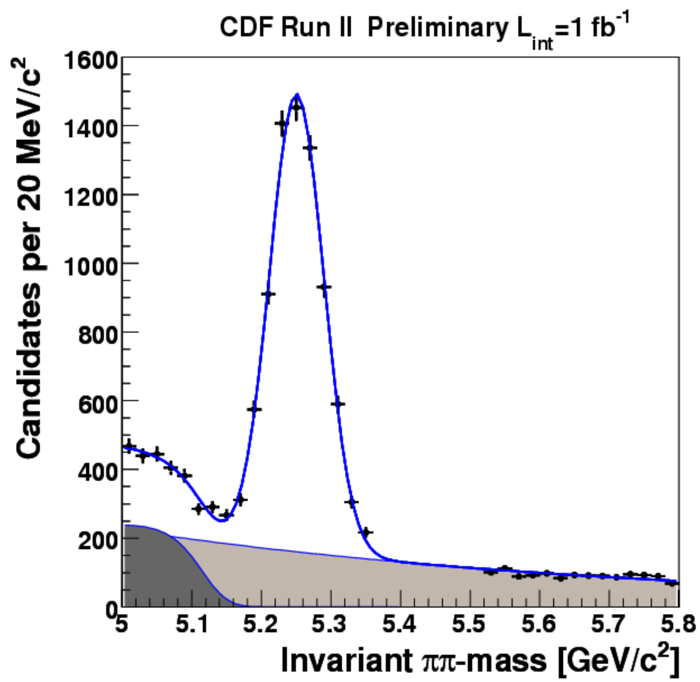


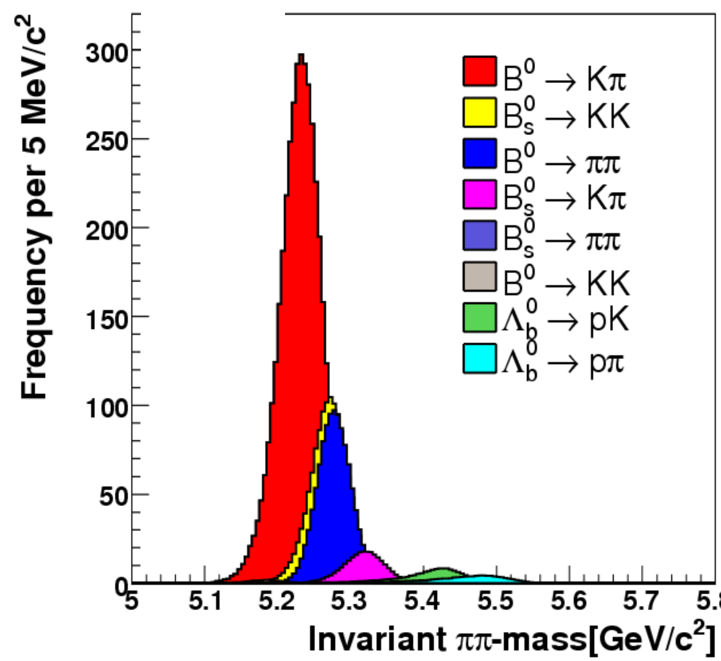






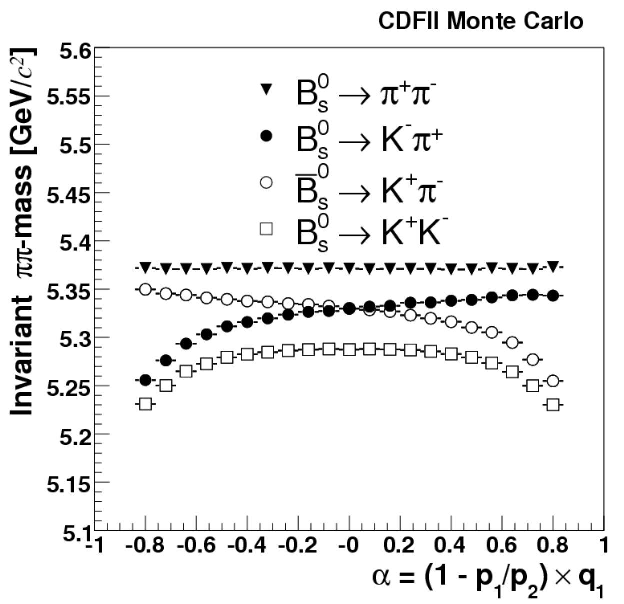
$B^0_{(s)} \rightarrow h^+h^{\prime -}$ - the second challenge

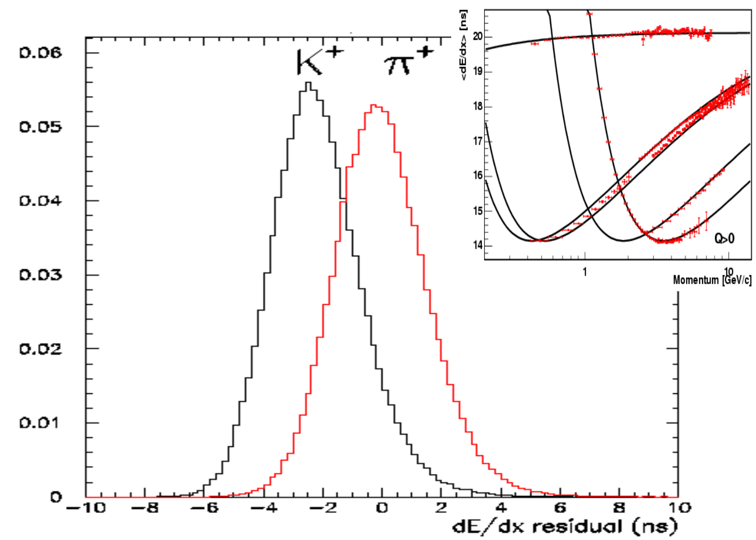




Insufficient mass and PID resolution to discriminate decay modes on a per-event basis

$B^0_{(s)} \to h^+h'^-$ - depuzzling sample composition





Any (arbitrary) mass assignment correlated with and momentum imbalance

Output pulse-width of 96 COT samplings $\propto$ log(Q). 1.5σ K/π separation at p>2 GeV/c

Statistical separation using kinematics and PID folded in a 5-dimensional ML fit.

$B^0_{(s)} \to h^+h'^-$ - a model independent NP test

Unitarity of CKM matrix implies: $\mathrm{Im}(V^*_{ub}V_{us}V_{cb}V^*_{cs}) = -\mathrm{Im}(V^*_{ub}V_{ud}V_{cb}V^*_{cd})$,

It implies relation between differences of CP-rates that is valid only in the SM. Unambiguous check if DCPV is induced by NP vs SM amplitudes.

$$\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-) = \Gamma(B_s^0 \to K^-\pi^+) - \Gamma(\overline{B}_s^0 \to K^+\pi^-)$$

We measure:

$$\frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\overline{B}_s^0 \to K^+\pi^-) - \Gamma(B_s^0 \to K^-\pi^+)} = -0.83 \pm 0.41(stat.) \pm 0.12(syst.)$$

(-1 in the SM)

Still limited by statistics. Now, with 5x more data on tape promising chance to probe NP in these decays.